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14. ABSTRACT

The specific objective of this effort is to develop distributed detection, classification, and localization (DCL) algorithms suitable for application to the nonlinear inversion problems encountered in ocean acoustics that can be nested within an over-reaching system concept of a cooperative sensor network. Joint parameter estimation processes were developed wherein both target parameters and environmental acoustic parameters (primarily bottom geoacoustic) are estimated. The latest tracking work incorporated a likelihood surface formulation with the JPDA algorithm.

We've determined that work is still needed to improve the performance of the JPDA algorithm with the likelihood surface formulation. Results were encouraging for the baseline tracking scenario where the truth is known. An initial framework for creating target times series associated with a contact-based tracking data set was expanded and a physically-motivated feature set and classifier was improved with the addition of classification.

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Distributed Environmentally-Adaptive Detection, Classification, and Localization Using a Cooperative Sensor Network

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LONG-TERM GOALS

The long-term goal of this research effort is to develop algorithms for environmentally adaptive ASW sonar signal processing for a distributed network of active acoustic sensors, and to validate the algorithms with simulation and at-sea test data.

OBJECTIVES

The specific objective of this effort is to develop distributed detection, classification, and localization (DCL) algorithms incorporating environmental inversion. These algorithms will be suitable for application to the nonlinear inversion problems encountered in ocean acoustics, and will be nested within an over-arching system concept of a cooperative sensor network. As such, this effort will address some of the unanswered scientific issues at the heart of the deployment and operation of a distributed sensor network.

APPROACH

In difficult acoustic environments, sonar signal processing algorithms can benefit from in-stride ocean acoustics parameterization. The results of the ONR Uncertainty DRI have shown that probabilistic trackers can benefit from incorporating better information about the environment, specifically through sonar performance prediction. Therefore, knowledge of the environment can lead to more accurate state estimation of the target's position and velocity. Accordingly, in this effort we are developing joint parameter estimation processes wherein both target parameters and environmental acoustic parameters (primarily bottom geoacoustic) are estimated. Recent work has focused on target tracking algorithms, target parameter estimation (*i.e.* physically motivated feature extraction), combining classification and tracking (feature aided tracking), and validation of the algorithms on simulated and real-world active sonar data.

WORK COMPLETED

1. ENVIRONMENTALLY-ADAPTIVE MULTI-STATIC TRACKING

The latest tracking work has been to incorporate a likelihood surface formulation (Fig. 1) with the JPDA algorithm, which was tested on the Metron data set. The Metron data set is a simulated data set and is designed to be very difficult with large bearing and range errors which leads to high localization error for true detections. There are also significant amounts of clutter. Results using other data association algorithms such as the PDA, PDAFAI, and PDAFAIwTS were not good, which led to the use of a likelihood surface. The preprocessing step using the likelihood surface is key for achieving reasonable results. For the baseline tracking scenario where the truth is known, the results were encouraging. Extending this technique to include acoustic modeling and Doppler information will be topics of future research.

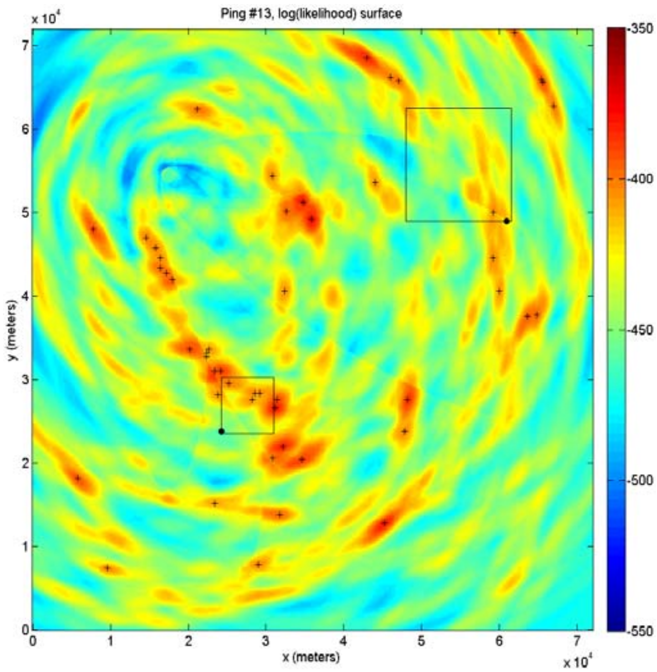

Fig. 1: The log of the likelihood surface for ping #13 of the Metron data set. The large black boxes are the true target paths. The true locations for two of the targets are plotted with the black dots. The black plus signs are the 30 maxima of the likelihood surface

2. FEATURE-AIDED TRACKING

A new direction in the recent years of this project has been to incorporate physics based classification of target echo time series into the tracker. The existing tracker uses a simple model for target and clutter based only upon distributions of target strength. A key challenge here has been the availability of multistatic tracking data offering the complete time series returned to each receiver as much of the work in this area has traditionally been done with target strength alone.

To overcome this hurdle, we have constructed full 3d target models using BASIS 3D in which returns can be generated. In order to add environmental effects, which are not represented by BASIS

3D, we use the Sonar Simulation Toolkit (SST). This mock up allows us to generate ping time series from any aspect angle which makes possible the development of aspect-dependent classification features and models. Both target and clutter pings can be simulated for any tracking data set which is lacking in time series data, *e.g.* the Metron data set.

The classifier used is relatively simple. We begin by considering the variations in the envelope (absolute value of the basebanded version) of the target return time series as the target's aspect angle changes, as illustrated for our BASIS-3D target model and a monostatic geometry in Figure 2. The effects of various parts of the target are clearly visible here, and these should be useful in distinguishing targets from clutter. Hence, our classifier uses time series like those in the plot as "templates" for detecting targets in test time series.

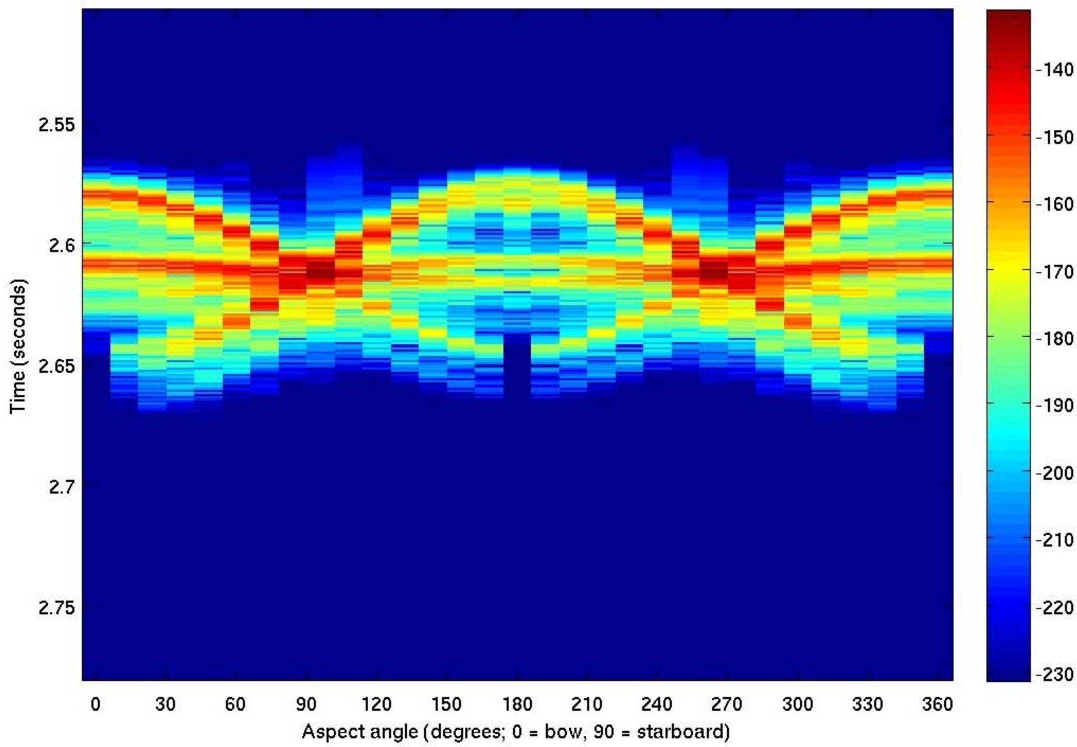

Figure 2: An image plot of target echoes in the time domain over 360° of aspect using BASIS 3D and SST in a deep water environment. Individual target components such as the sail, bow and tail fin can be resolved.

Since the returns are strongly dependent on aspect angle and bistatic angle, the classifier attempts to explicitly account for this by using templates generated for 500 different geometries (for each known target type): namely, the 100 aspect angles {0, 3.6, 7.2, ..., 356.4}° for each of the 5 bistatic angles {0, 30, 60, 90, 120}°. The known target types are the "generic" and "diesel" models from the original 2-D version of BASIS.

The classifier takes the cross-correlation (in time) between the test signal and each template, normalized so that the maximum possible value is 1, and then takes the maximum over time for each template and then the maximum over all templates. We then take the reciprocal of this maximum normalized cross-correlation to be the "distance" between the test signal and the chosen template signal. Finally, the classifier uses 40-point histograms (one for targets and one for clutter) of the “distance” in training data to estimate the likelihood of the test signal being a target and the likelihood of it being clutter, and these likelihoods are output to the tracker. (Preliminary experiments not further described here were run using kernel density estimation instead of histograms to estimate likelihoods, but produced essentially no difference in the results.)

Since each template is explicitly associated with a bistatic angle and an aspect angle (namely, the angles used to generate the template), one might wish the system to take advantage of this information. In the case of the bistatic angle, the classifier could consider only templates with a bistatic angle close to that of the contact associated with the time series to be classified. However, in preliminary experiments not further described here, this method did not meaningfully improve classification performance at bistatic angles below 90°, and meaningfully degraded performance at bistatic angles above 90°. Similarly, the aspect angle of the template with the highest correlation constitutes an estimate of the aspect angle of the target that produced the test signal, and this estimate could then be fed into the tracker as a piece of kinematic information that is independent (at least in a loose sense) from the contact positions. However, this remains as future work.

RESULTS

The likelihood surface formulation (Fig. 1) was applied to the Metron data set. The significant amounts of clutter make it a very difficult data set and there is still work to be done to improve the performance of the JPDA algorithm with the likelihood surface. For the baseline tracking scenario where the truth is known, the results were encouraging. Extending this technique to include acoustic modeling and Doppler information will be topics of future research.

An initial framework for creating target times series that are associated with a contact-based tracking data set has been expanded, and a physically-motivated feature set and classifier has now been incorporated into the tracker. Results on an initial data set (TNO dataset) showed minimal improvement with the addition of classification. However the TNO dataset was a relatively easy data set on which the tracker performed well even without a sophisticated classifier. Work on the more challenging Metron data set is ongoing.

IMPACT/APPLICATIONS

This effort will develop useful methods for distributed DCL that will have broad applicability to distributed ASW systems. Results of this work will be applicable to current Air ASW systems such as EER/IEER/AEER, as well as future concepts such as the planned Placement of Active ASW Distributed Systems (PAADS) and the Operation of Active ASW Distributed Systems (OAADS) FNC.

RELATED PROJECTS

1. “Nonlinear inversion from nonlinear filters for ocean acoustics,” Robert I. Odom, supported by Dr. Ellen Livingston, Code 321OA, Office of Naval Research.
2. “Placement of Active ASW Distributed Systems (PAADS),” Robert Miyamoto, ONR FNC project supported by Dr. Ellen Livingston, Code 321OA, Office of Naval Research.
3. “Operation of Active ASW Distributed Systems (PAADS),” Marc Stewart, ONR FNC project supported by Dr. John Tague, Code 321, Office of Naval Research.
4. “Research and Development Tactical Mobile Acoustic Support System,” Robert Miyamoto, supported by Dr. John Tague, Code 321US, Office of Naval Research.

5. “Joint Signal Deconvolution and Classification”, Maya Gupta, Office of Naval Research Young Investigator Program (ONR YIP).

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9. D. W. Krout, J. Hsieh, M. Antonelli, M. Hazen, and G. Anderson, “3-D Filter method for Sensor Optimization”, Accepted for Publication, JUA.
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